Biophysical Climate Change Effects on Agro-ecosystems

U.S. EPA/DOE Workshop

Research on Climate Change Impacts and Associated Economic Damages

January 27-28, 2011

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Outline

- **Estimates of current and likely impact of climate change on biophysical response of agricultural crops**
- **Data and models used to make projections**
- **Modulation of biophysical impacts via adaptation**
- **Gaps and uncertainties**

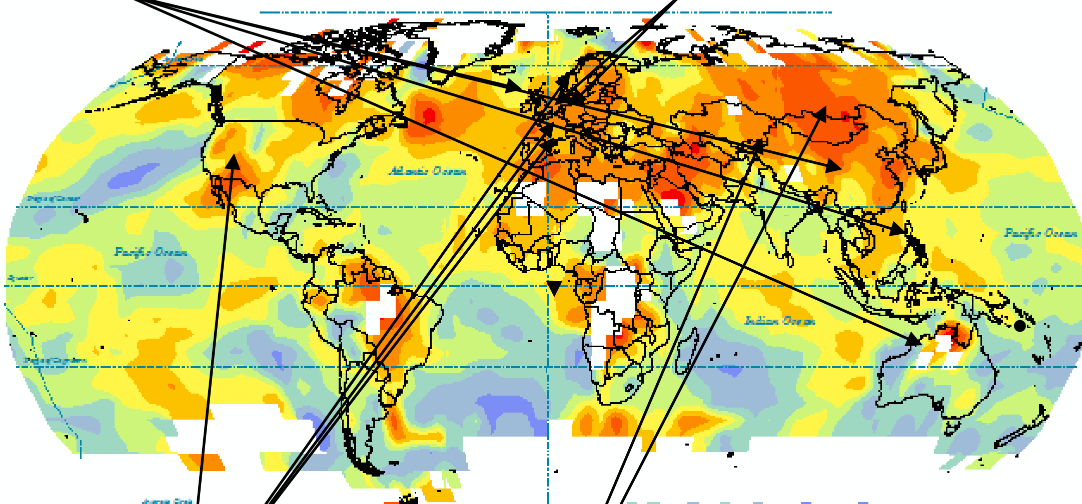
Current and Future Impacts

- Estimates of the current and likely future impact of climate change on biophysical response of agricultural crops.
  - What crops, (livestock), soil, and pests will be most affected?
  - Describe the best central estimates, the wider range of possible outcomes, and the relative likelihood of those outcomes.

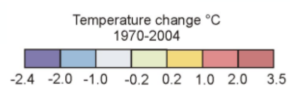
Observed Impacts on Agriculture

Yields

Phenology



1973-2002 Annual temperature trends
<-1.2C to >1.2C



Management practices, forest fires, earlier pests and diseases

Livestock

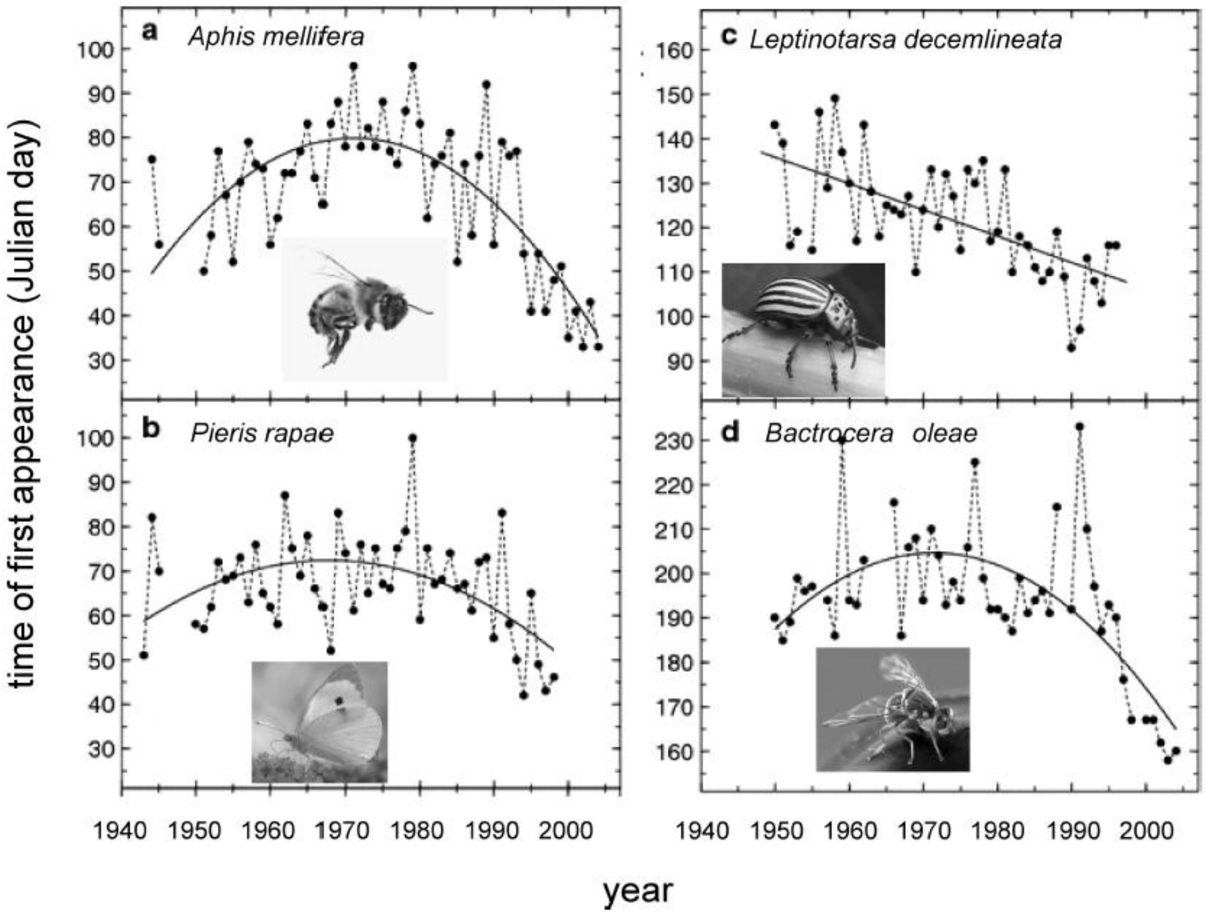
Over the last 50 years:

- ***Very likely***
  - **less frequent cold days, cold nights, and frosts**
  - **more frequent hot days and hot nights**
- ***Likely***
  - **more frequent heat waves**
  - **more frequent heavy precipitation events**
  - **increased incidence of extreme high sea level**
  - **increased drought in some regions**

High temperature effect on rice yield; Earlier planting of spring crops; Increased forest fires, pests in N America and Mediterranean; Decline in livestock productivity

IPCC WGII AR4

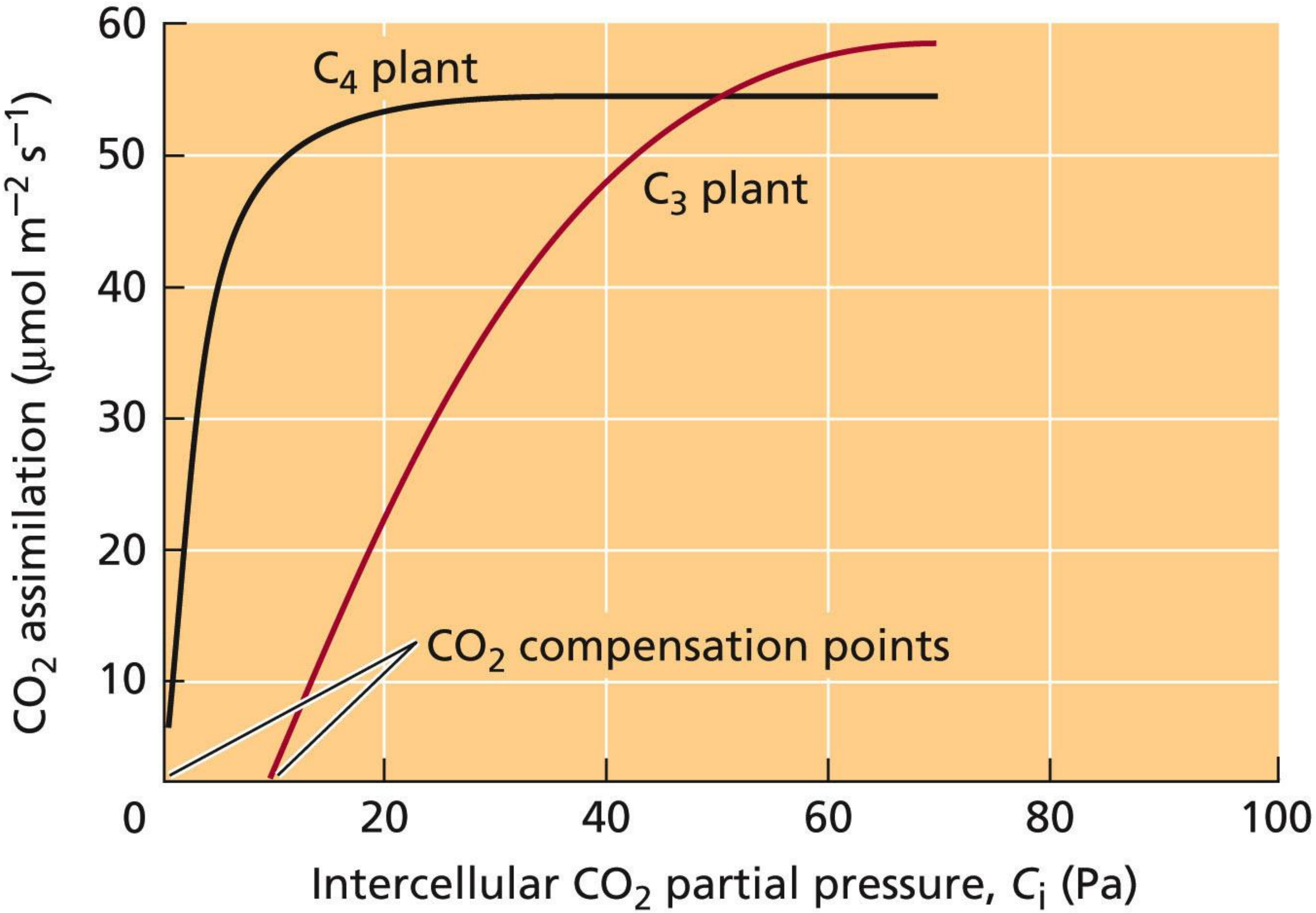
Earlier Emergence of Insects



In a six-decade long study at a biological research station in Spain, increasing earlier time of first appearance for the honey bee, cabbage white butterfly, potato beetle and olive fly were found.

Gordon and Sanz, 2005; Gutierrez et al., 2010

Photosynthesis Response to CO_2



C_3 Plants

Wheat

Rice

Soybean

Barley

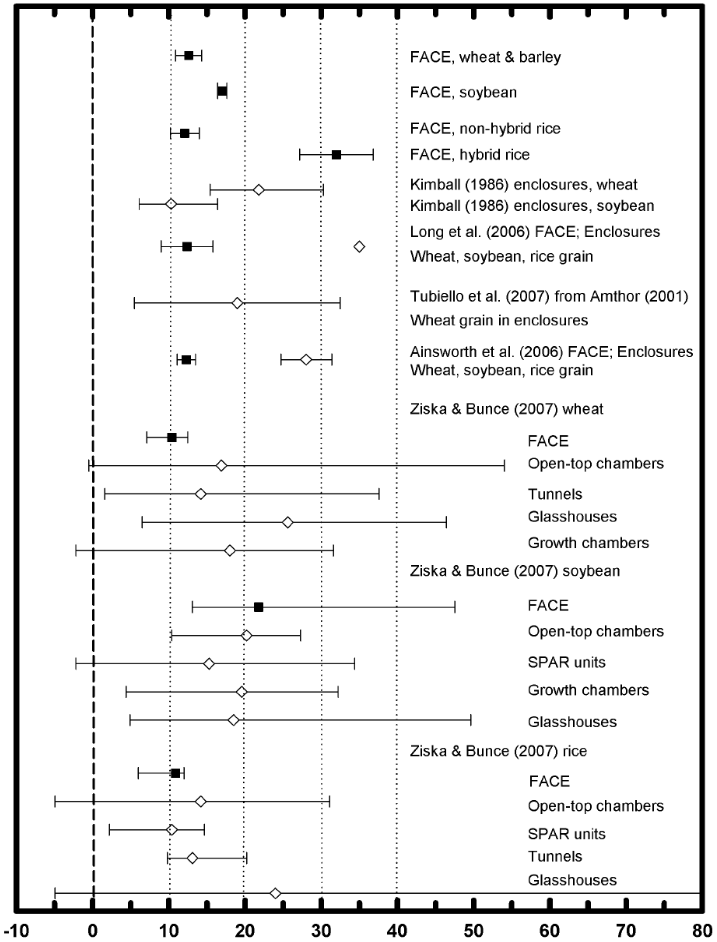
C_4 Plants

Corn

Sorghum

Sugarcane

CO_2 Yield Responses



Relative C3 crop yield changes due to elevated CO_2 (%)

- Biomass and yield with +200ppm were increased by FACE in C3 species, but not in C4 except under water stressed conditions. Average C3 yield increase is ~16% in FACE.
- Low soil N often reduces these gains.
- It appears unlikely that there is a significant difference in the response of C3 grain crops to elevated CO_2 between FACE and enclosure experiments when the whole population of enclosure experiments is included and their variability is accounted for.
- Important for simulation.

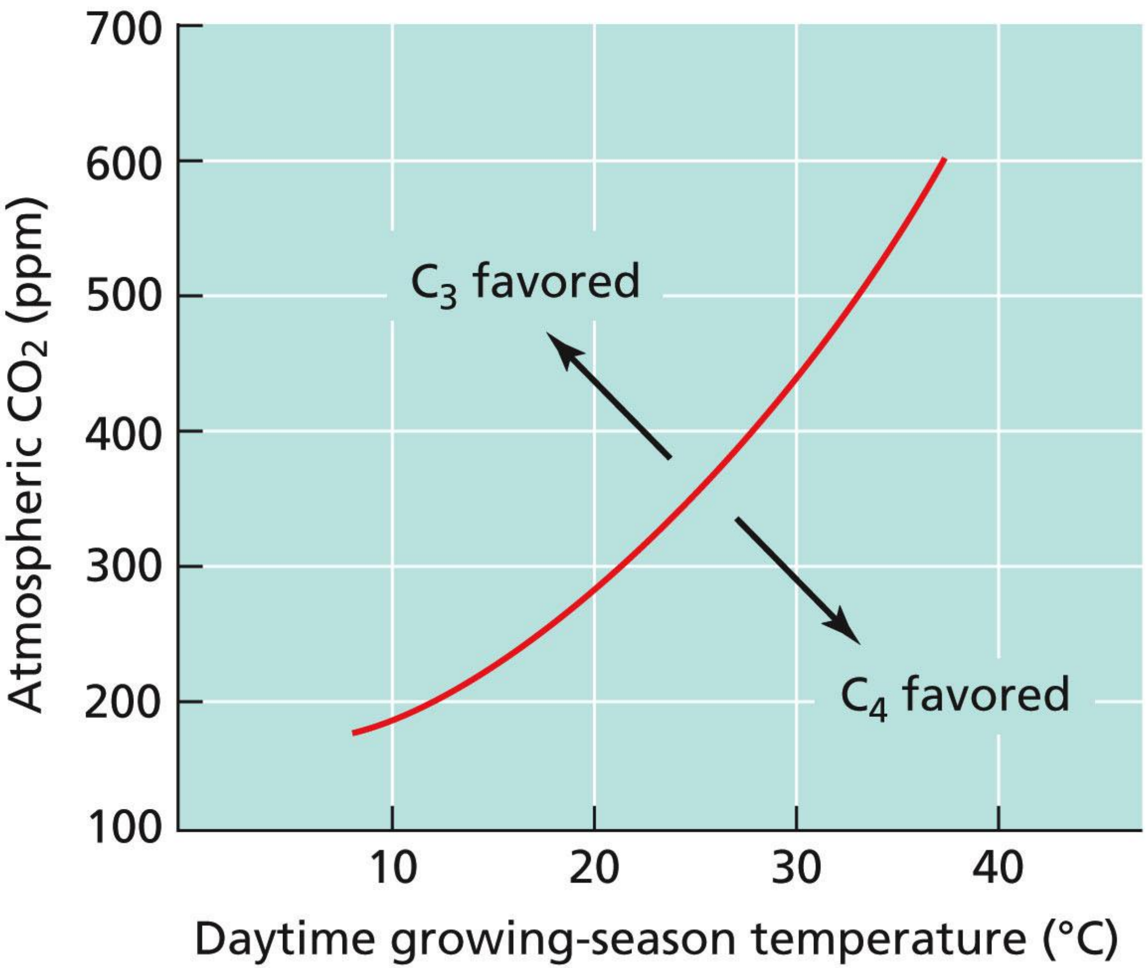
Kimball 2010

Elevated CO_2 can also favor weeds

Crop	Weed	Increasing $[CO_2]$ favors	Environment	Reference
A. C_4 Crops/C_4 Weeds				
Sorghum	*Amaranthus retroflexus*	Weed	Field	Ziska (2003)
B. C_4Crops/C_3 Weeds				
Sorghum	*Xanthium strumarium*	Weed	Glasshouse	Ziska (2001)
Sorghum	*Albutilon theophrasti*	Weed	Field	Ziska (2003)
C. C_3Crops/C_3 Weeds				
Soybean	*Chenopodium album*	Weed	Field	Ziska (2000)
Lucerne	*Taraxacum officinale*	Weed	Field	Bunce (1995)
Pasture	*Taraxacum and Plantago*	Weed	Field	Potvin and Vasseur (1997)
Pasture	*Plantago lanceolate*	Weed	Chamber	Newton *et al.* (1996)
D. C_3 Crops/C_4 Weeds				
Fescue	*Sorghum halapense*	Crop	Glasshouse	Carter and Peterson (1983)
Soybean	*Sorghum halapense*	Crop	Chamber	Patterson *et al.* (1984)
Rice	*Echinochloa glabrescens*	Crop	Glasshouse	Alberto *et al.* (1996)
Soybean	*A. retroflexus*	Crop	Field	Ziska (2000)

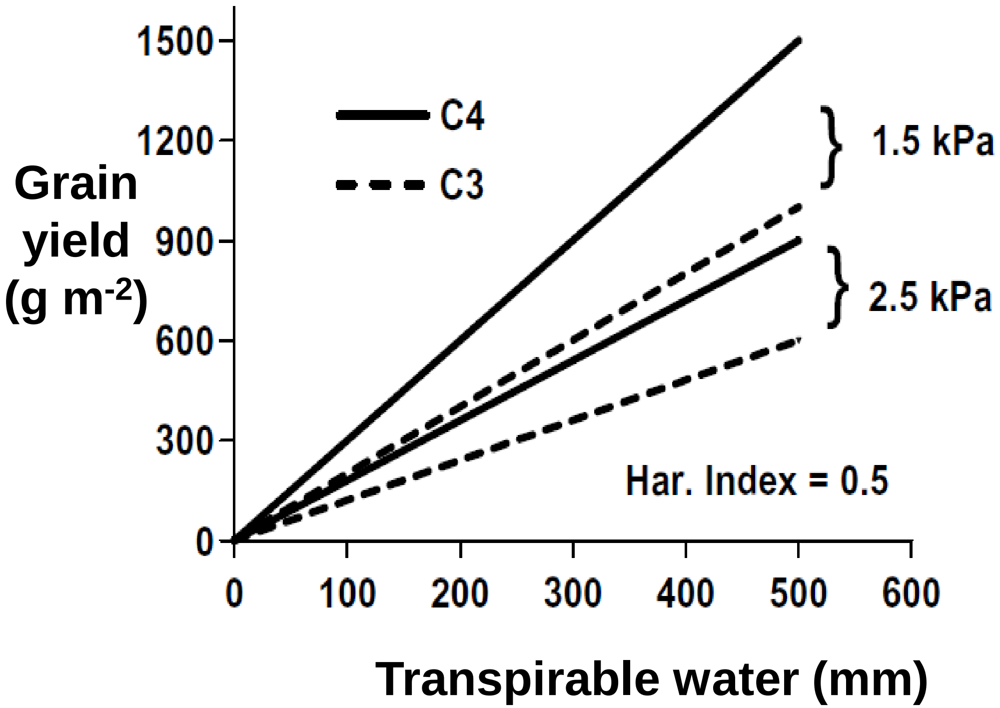
Ziska 2010

Crop Response to Temperature



- Can shift photosynthesis curve positively
- Speed-up of phenology is a negative pressure on yield
- High-temperature stress during critical growth periods
- T-FACE experiments now underway.

Yield Response to Water
Extreme events – Drought

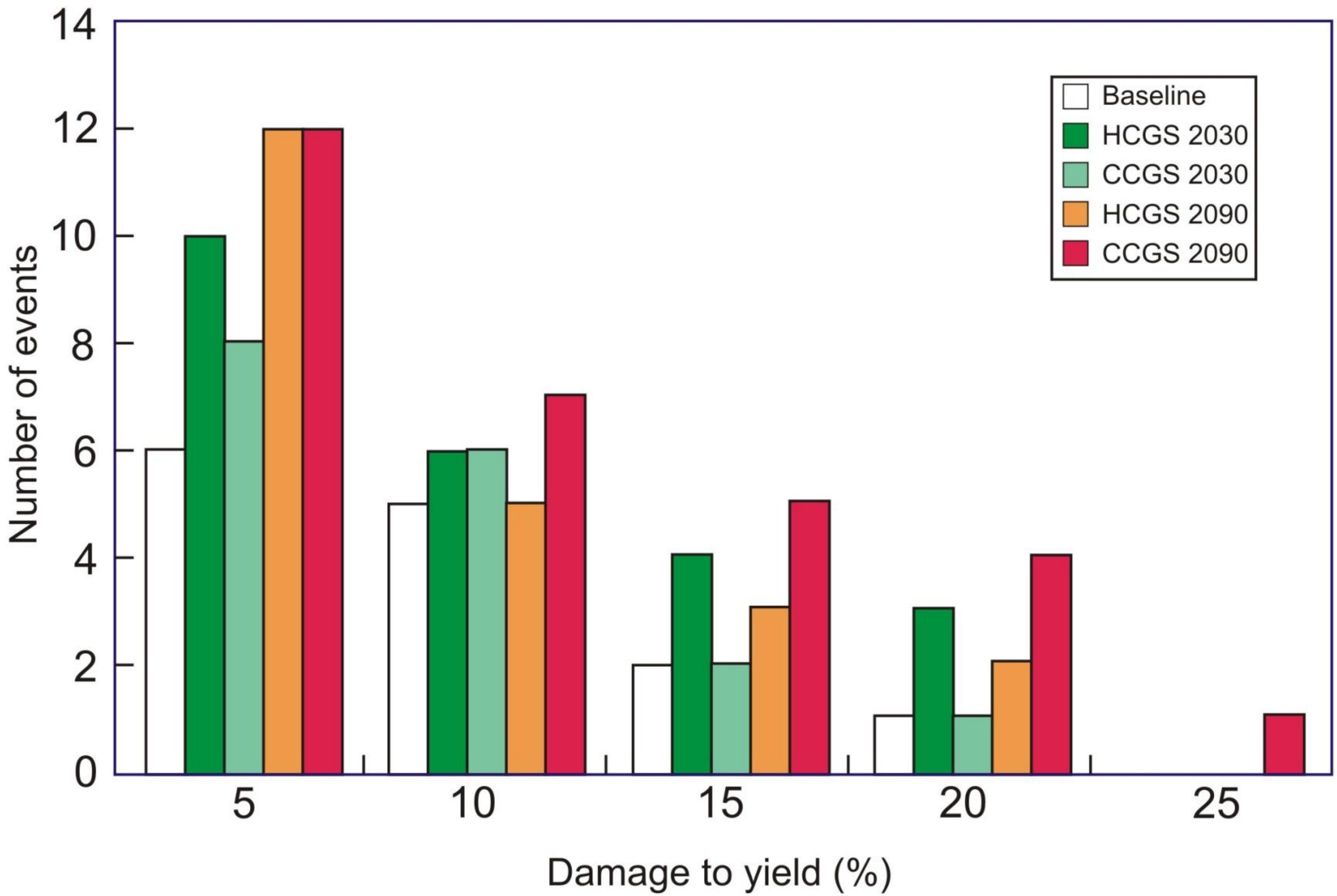


Maximum grain yield plotted as a function of the amount of transpirable soil water available through the growing season. Two vapor pressure deficit environments are presented. C4 crops favored at both higher and lower water stress.

- Crops need water – through precipitation or irrigation
- Drought stress affects yield during critical growth periods
- Excess water can be damaging as well

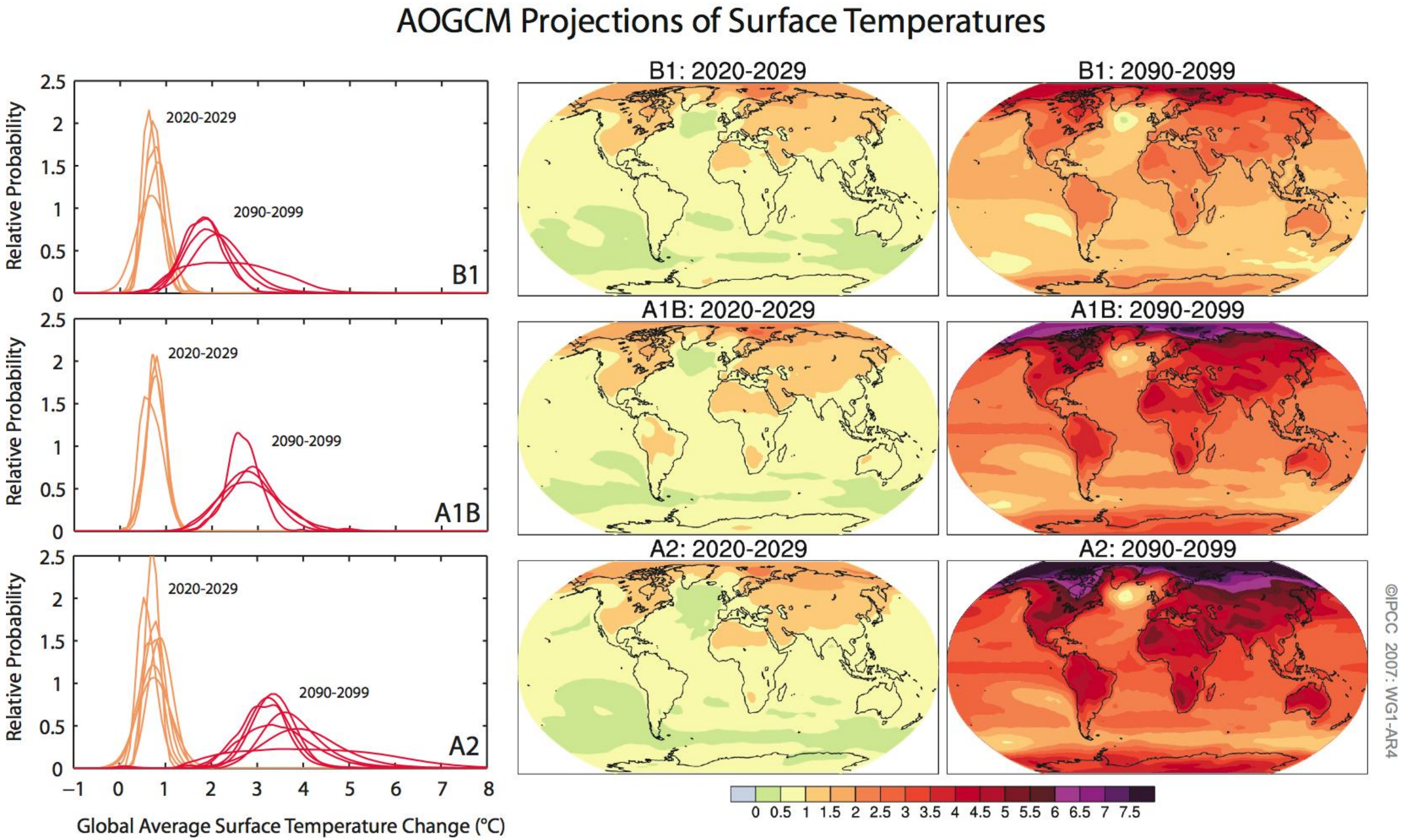
Sinclair 2010

Extreme Events – Floods



Number of events causing damage to maize yields due to excess soil moisture conditions, averaged over all study sites, under current baseline (1951–1998) and climate change conditions. Events causing a 20% simulated yield damage are comparable to the 1993 US Midwest floods.

Rosenzweig et al. 2001

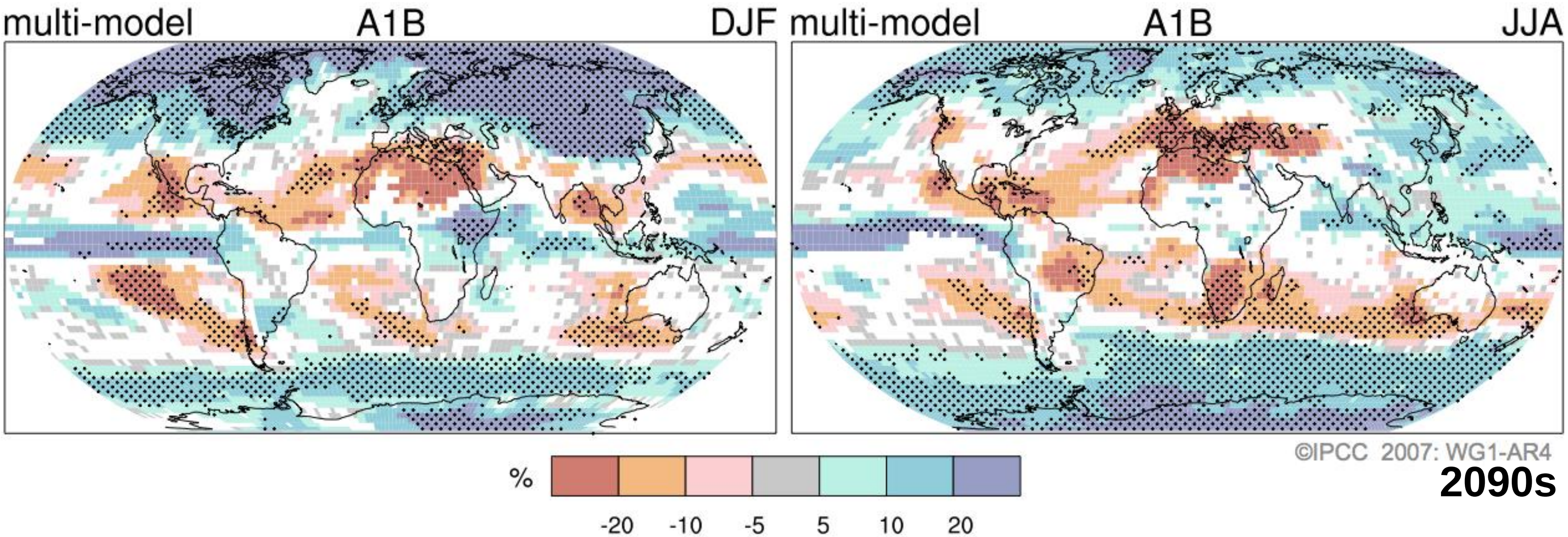


Warming is Expected to be Greatest over Land and at Most High Northern Latitudes.

Hot Extremes and Heat Waves will Continue to Become More Frequent

IPCC WGII AR4 Fig SPM-6

Projected Patterns of Precipitation Changes



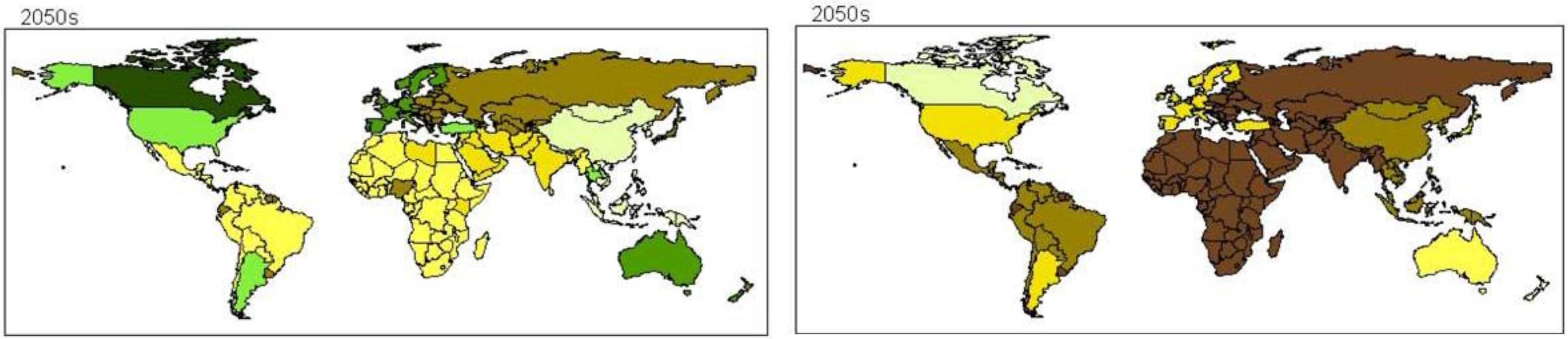
Increases in Precipitation are Very Likely in the High-Latitudes, while Decreases are Likely in Most Subtropical Land Regions

Heavy Precipitation Events will Continue to Become More Frequent

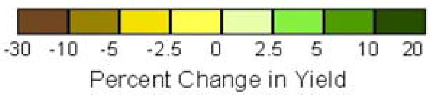
Droughts more frequent in some regions

IPCC WGI AR4
Figure SPM-7

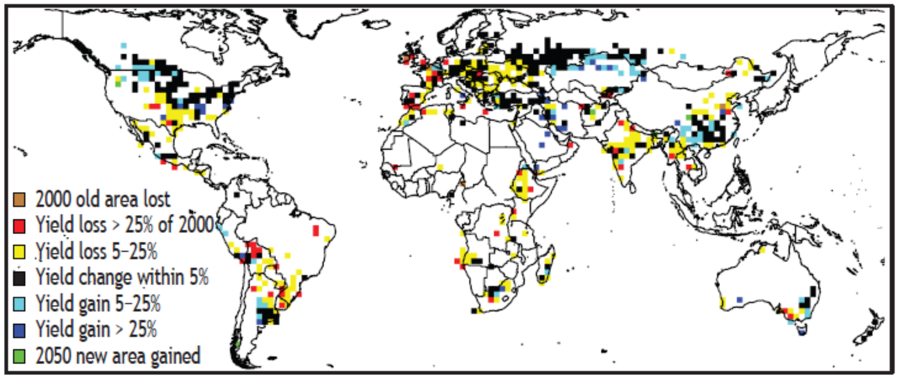
Projected Yield Changes 2050s



Parry et al., 2004



Potential changes (%) in national cereal yields for the 2050s (compared with 1990) under the HadCM3 SRES A2a scenario with and without CO_2 effects (DSSAT)



IFPRI 2011

Yield Effects with CO_2, rainfed wheat CSIRO A1B (DSSAT)

Parry et al.	-30% to +20%
IFPRI	-25% to +25%
GAEZ	-32% to +19%

GAEZ IIASA 2009 rain-fed cereals Hadley A2
North America -7 to -1%; Europe -4 to 3;
Central Asia 14-19%; Southern Africa -32 to -29

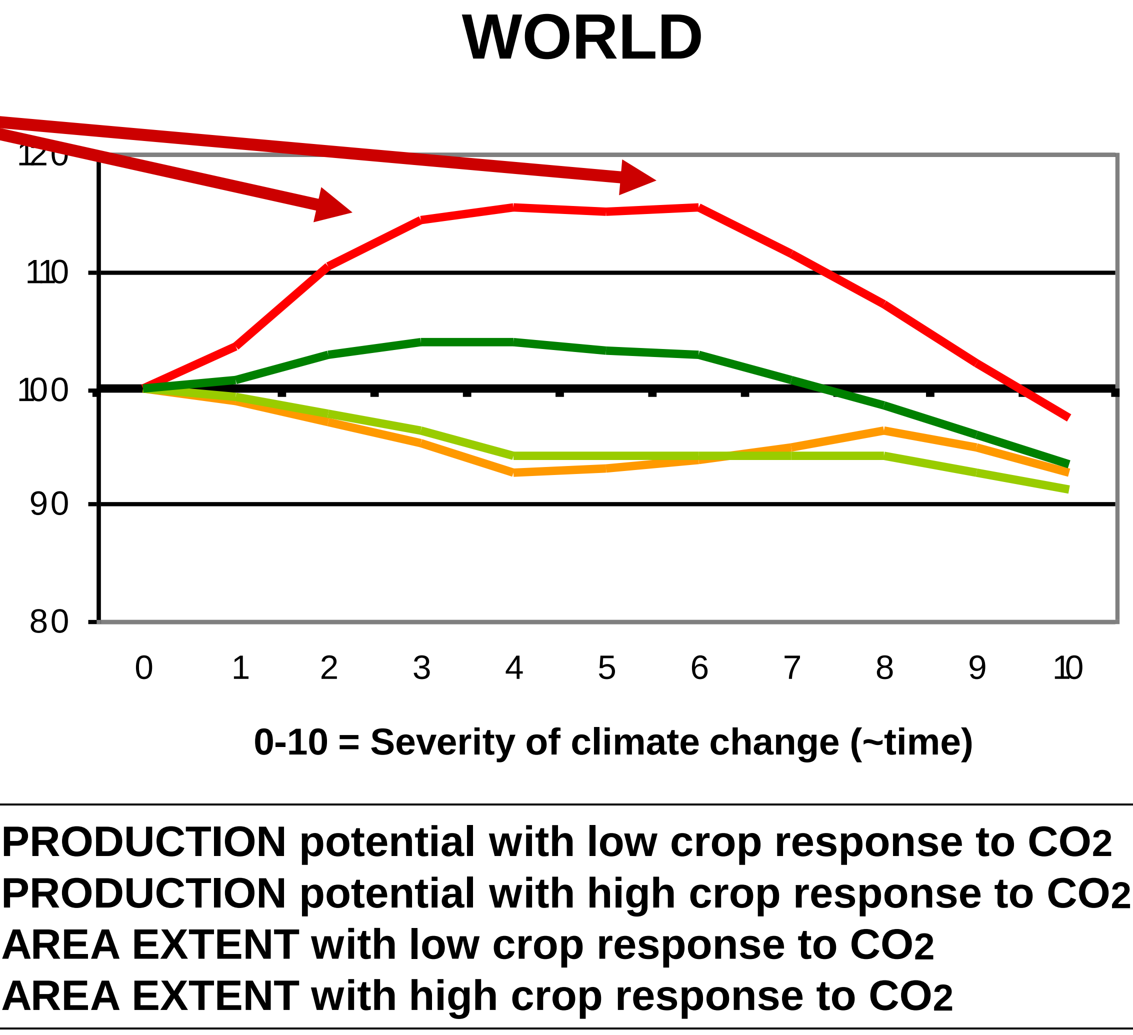
Schlenker & Lobel Africa multi GCMs
-22 to -2% statistical approach

w/o adaptation

Global Effects of Climate Change are Positive in Short Term and Negative in Long Term

Percent Change in Food Production Potential

Inflection Points ???



IIASA

Discuss the data and models used to make these projections.

Are some modeling methods superior to others?

What are the main data requirements, spatial resolution, and level of uncertainty in the outputs?

How are impacts expected to differ across temperate and tropical regions?

Statistical Approach

- Uses historical data to estimate statistical relationships between observed crop yields as a function of observed climate variables.
- Uses these relationships to project the yield impact of changes in climate.

Advantages

Relationships should integrate biophysical responses to climate variables; based on observations; data availability is improving.

Disadvantages

The approach does not explain process-based changes; does not represent out-of-sample conditions; does not incorporate the effects of CO_2.

Data: yearly yield/aggregated 1° 4-hourly reanalysis, monthly, growing season, degree days climate; Spatial resolution: crop reporting districts; country level

Expert System Approach

• Uses soil capability, climate, crop calendar, and simple productivity relationships to estimate production potential of agricultural systems.

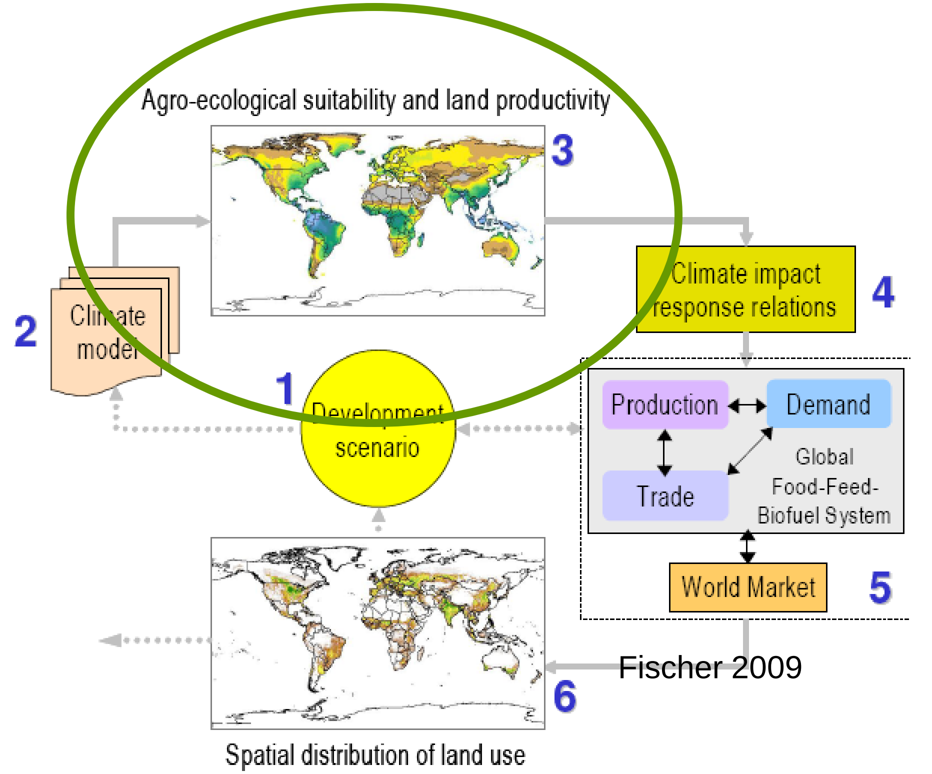
• Use calculator to project effect of changes in climate on production potential.

Advantages

Projects changes in both production potential and spatial extent of cropping systems; global extent.

Disadvantages

Results not easily validated in current climate.
Processes are represented by simplified relationships.



Fischer 2009

GAEZ Data: yearly yield/monthly climate; soils; crop calendars; ag systems;
Spatial resolution 5’x5’ lat/long

Dynamic Process Crop Models

Advantages

• Explicit simulation of processes affected by climate, including CO_2 effects on growth and water use.

• Management practices included.

• Cultivar characteristics can be tested for 'design' of adapted varieties.

• Testable with experimental field data.

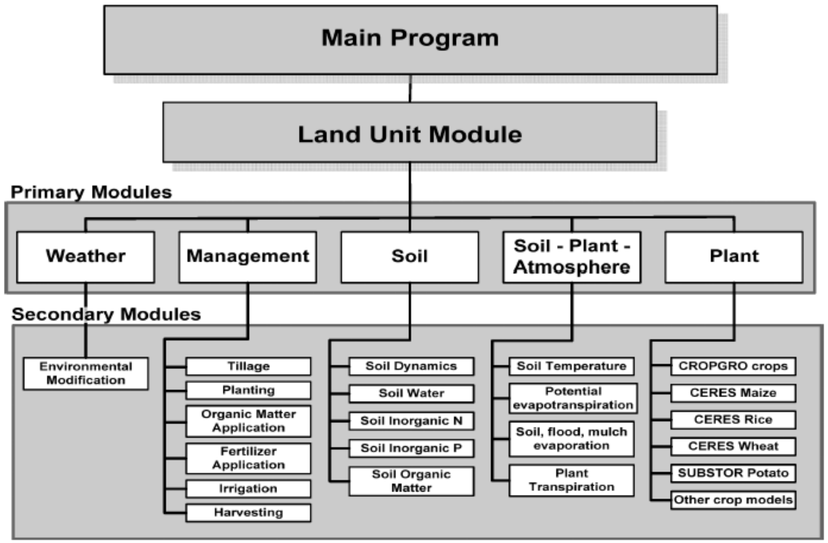
Disadvantages

• Not all biophysical processes included.

• Aggregation from sites to regions challenging.

• Data availability varied.

Data: daily T, P, SR; cultivar characteristics; soils, management; yearly yield
Spatial resolution: Site-based; aggregated to regions, countries



Jones 2010

Cereal Yield Response to Warming Temperate vs. Tropical Regions

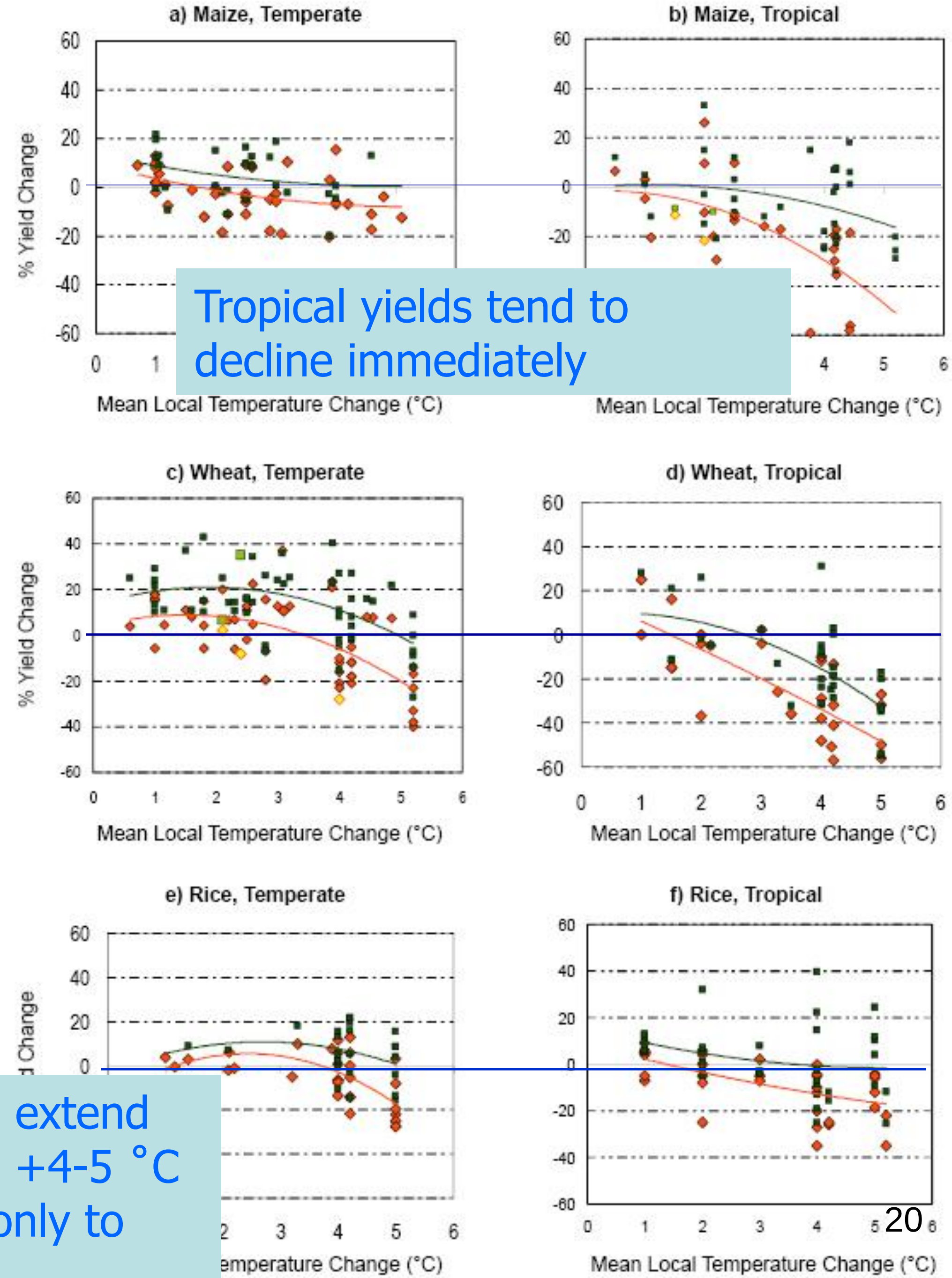
With and Without Simulated Adaptation

Temperate yields tend to thrive until +3˚C

Red = without adaptation

Green = with adaptation

—— = reference line for current yields

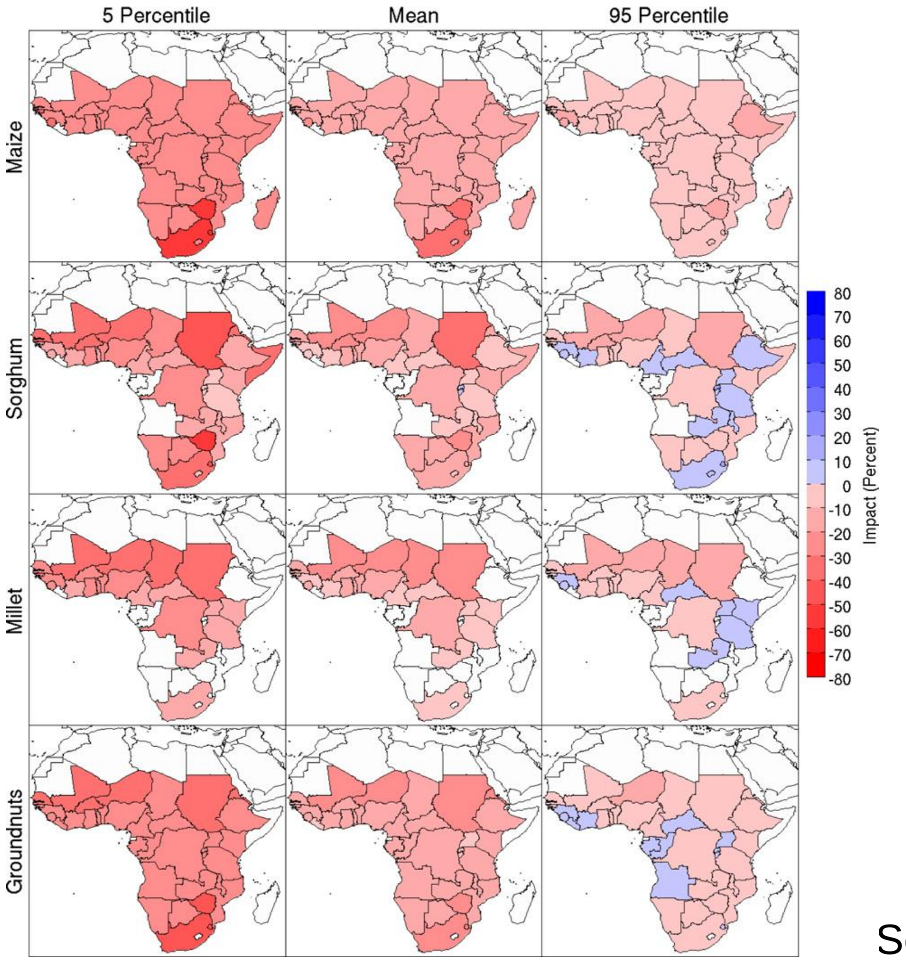


Tropical yields tend to decline immediately

Simple adaptations extend temperate crops to +4-5 ˚C but tropical yields only to +2-3˚C

IPCC, 2007

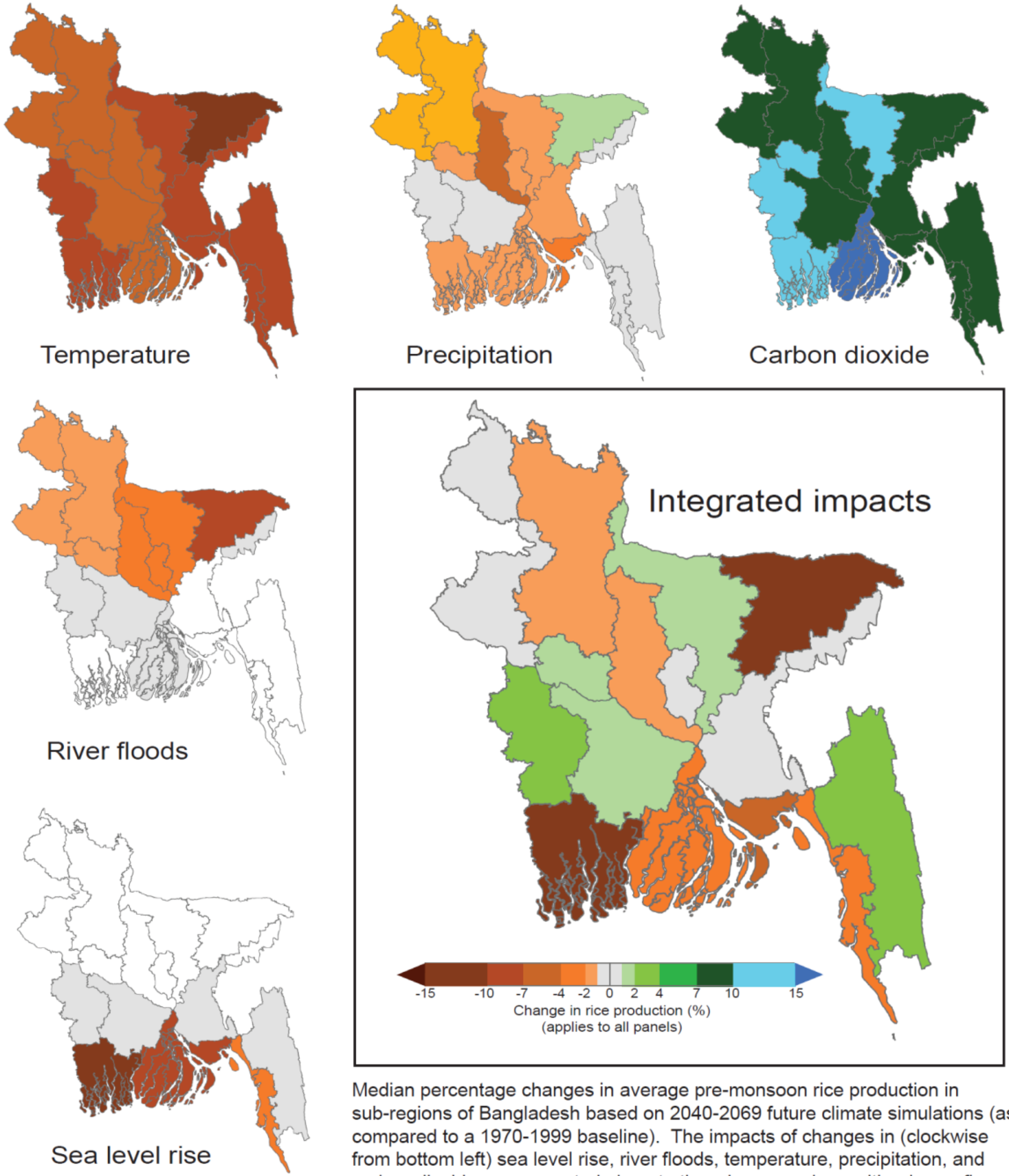
Projected Changes in Aggregate Cereal Production in Sub Saharan Africa from Climate Change in 2046-2065



- The benefits of adaptation are uncertain.
  - A portfolio of strategies are recommended
  - (e.g.) creating crops for both drought and heat tolerance
- There is a need to reduce the uncertainty in how effective different interventions are.
  - It is recommended to accelerate efforts to monitor and evaluate current activities toward adaptation.

Schlenker Lobell 2010

Projected effects of climate change factors on Bangladesh rice production in the 2050s



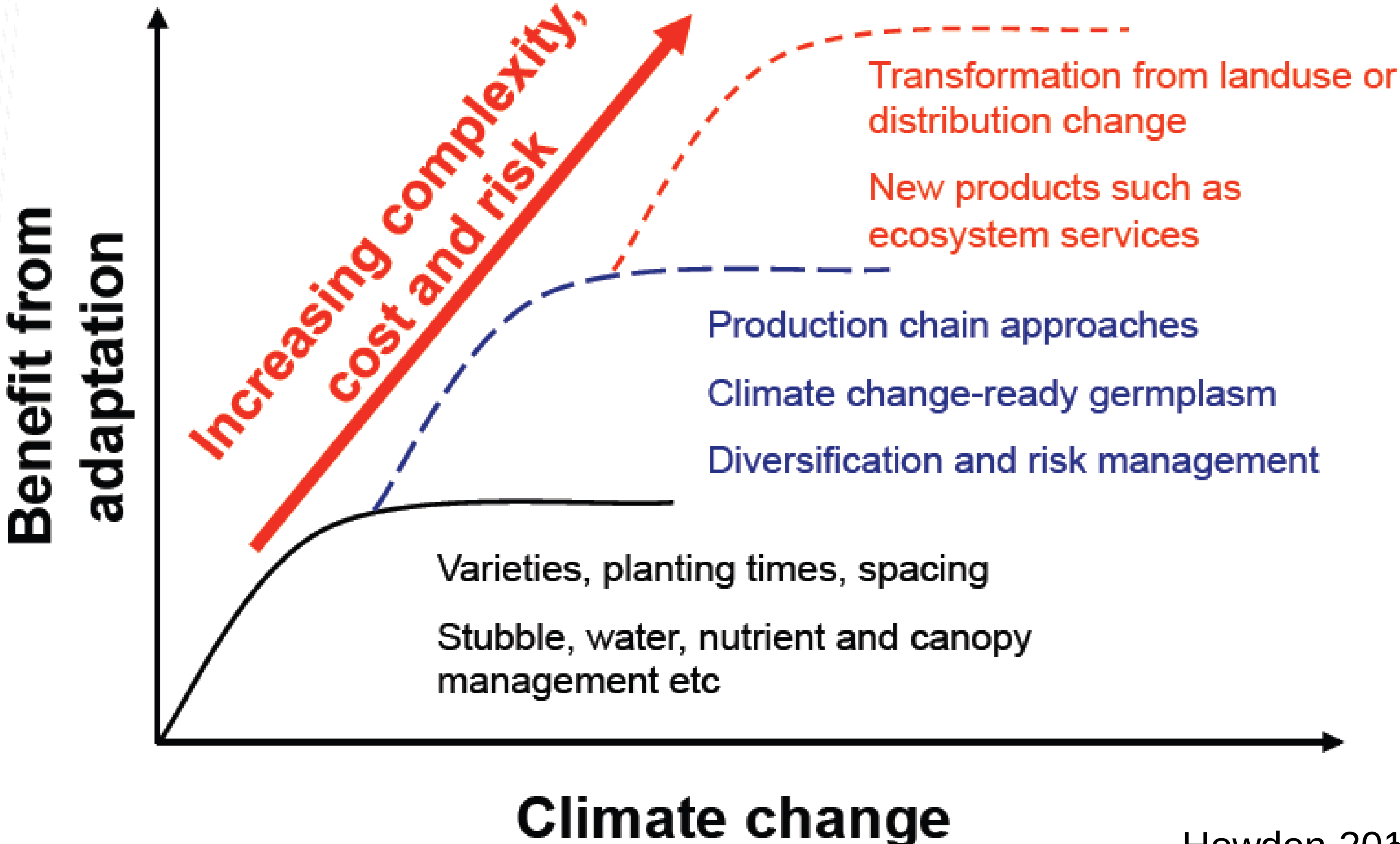
Median percentage changes in average pre-monsoon rice production in sub-regions of Bangladesh based on 2040-2069 future climate simulations (as compared to a 1970-1999 baseline). The impacts of changes in (clockwise from bottom left) sea level rise, river floods, temperature, precipitation, and carbon dioxide are presented absent other changes, along with a larger figure showing the integrated production changes when all impacts are considered.

Ruane et al., 2009; World Bank, 2009, Forthcoming

To what extent are changes in agricultural practices and technologies capable of modulating biophysical impacts?

Progressive Levels of Adaptation

Challenges and Opportunities



Howden 2010

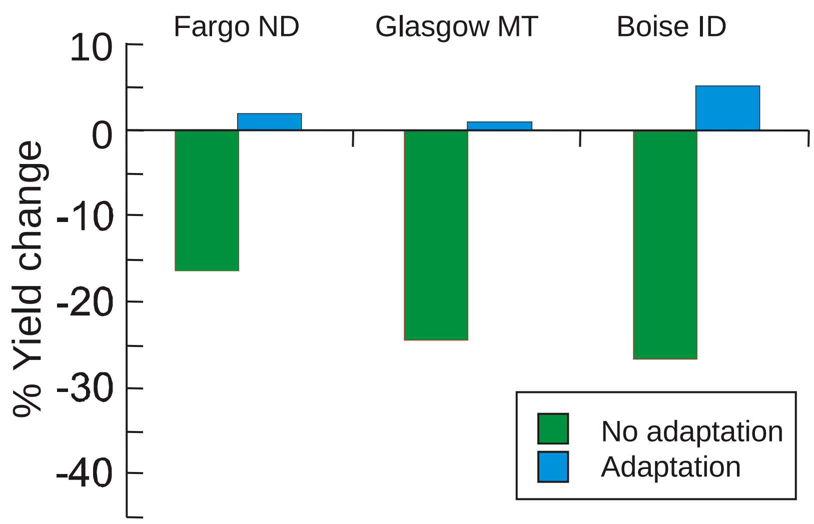
Adaptation is Not Always Possible or Complete

Two examples for the CCGS 2030s Scenario

Spring wheat

Strategy: Early planting

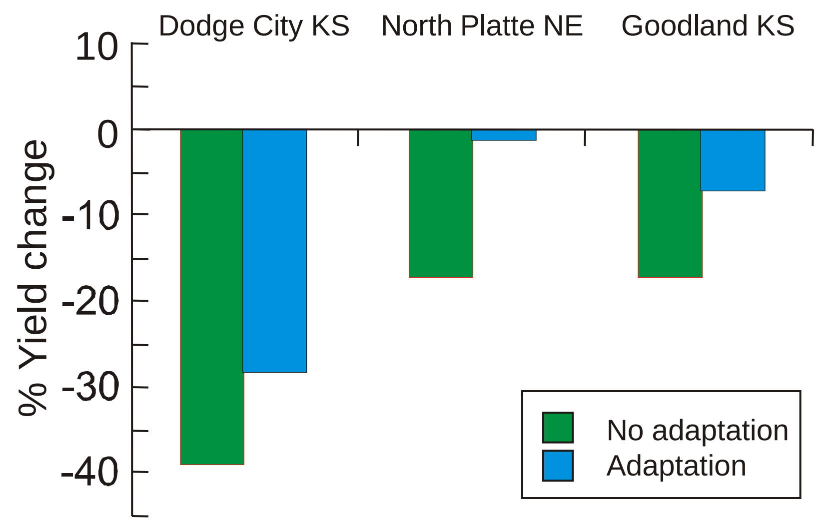
Results: Successful heat stress avoidance



Winter wheat

Strategy: Change of cultivar

Results: Unable to reverse damage due to low precipitation



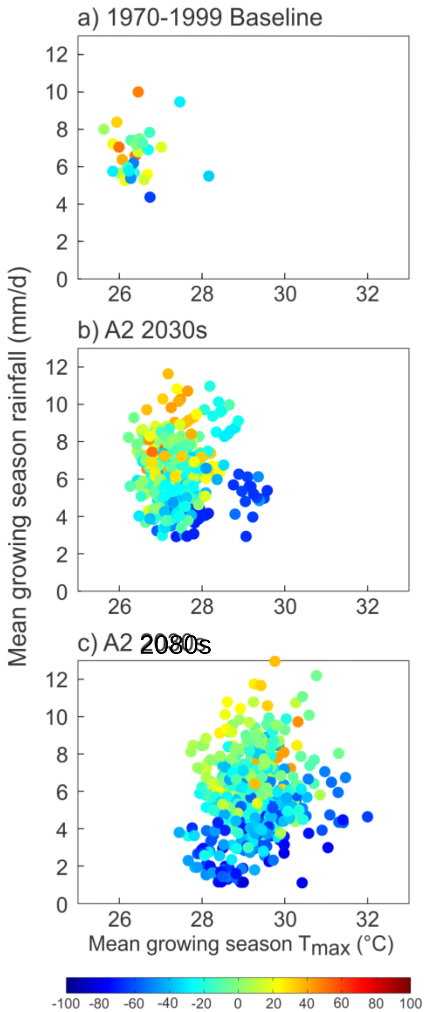
CC = Canadian Climate Centre GCM

U.S. National Assessment; Tubiello et al., 2002

What are the most important gaps or uncertainties in our knowledge regarding biophysical responses of agro-ecosystems to climate change?

What additional research would be most valuable?

Gaps and Uncertainties

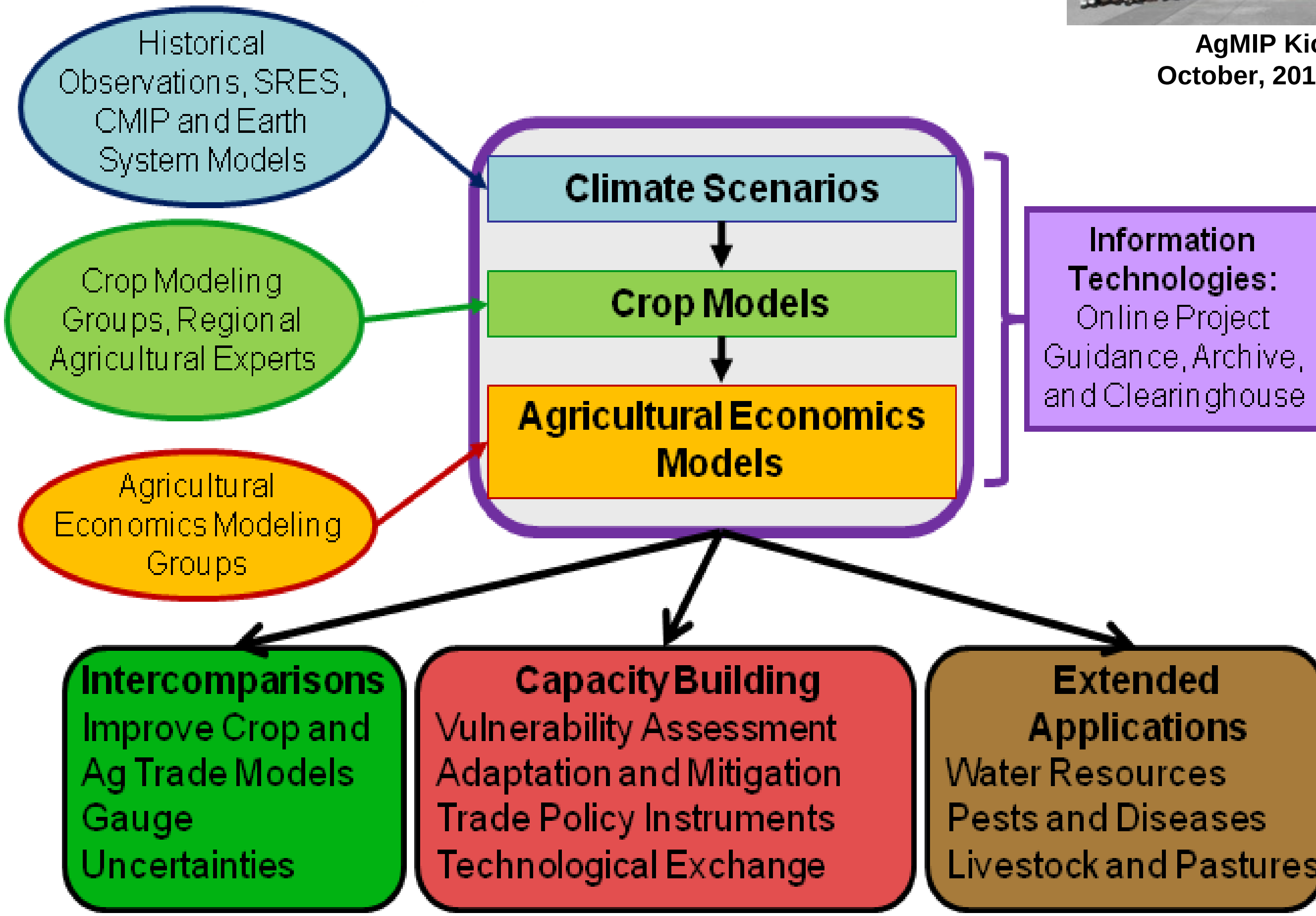


Simulated yield (as % change from 1970-1999 mean) sensitivity under constant CO_2 versus various climate metrics. Panama

- **Precipitation!**
- **Models and methods are still constrained in their ability to simulate extreme weather events.**
- **The interactions of warmer temperature with CO_2 and ozone need continued experimental research and simulation development.**
- **Effects of changes in evapotranspiration on soil moisture and crop yield and wider interactions with water availability is poorly understood.**
- **Pests**
- **Scale of simulation influences results.**
- **Yield gaps and plateaus.**
- **Lack of multi-model comparisons and assessments.**

AgMIP The Agricultural Model Intercomparison and Improvement Project

AgMIP Kickoff Workshop
October, 2010 Long Beach, CA



AgMIP components and expected outcomes

Aggregation, Uncertainty, Agricultural Pathways